genera *Azotobacter* and *Azotococcus* as a homogenous group. The acid-forming non-symbiotic N-fixing bacteria are excluded and classified separately. The genus *Beijerinckia* is accepted for *Azot. indicum* and *Azot. lacticogenes.*

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STUDIES IN THE METAMORPHIC AND PLUTONIC GEOLOGY OF THE WANTABADGERY–ADELONG–TUMBARUMBA DISTRICT, N.S.W.

Part I. Introduction and Metamorphism of the Sedimentary Rocks.

By T. G. Vallance, Linnean Macleay Fellow of the Society in Geology.*

(Plates v-vi; nine Text-figures.)

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Synopsis.

An area consisting mainly of miogeosynclinal sediments (partly, at least, of upper Ordovician age) and plutonic masses is discussed. The sediments, typically pelites and psammo-pelites, suffered a metamorphism which was regional in extent yet had an important thermal aspect. Variations in metamorphic intensity are represented by isogradal lines introducing the several zones established here. The metamorphic progression is from (1) a low-grade zone (with chlorite-muscovite slates and phyllites) characteristic of the country rocks of the region to (2) a biotite zone, followed by (3) a knotted schist zone (with andalusite and/or cordierite porphyroblasts) which passes into (4) a high-grade zone where the sediments become granulites which, in places, carry sillimanite and potash felspar. The zones are fairly evenly distributed around the Wantabadgery and Green Hills granite masses but do not display any constant relation to the other granites. In proximity to acid veins from the Wantabadgery and Green Hills granites the metasediments may be enriched in brown tourmaline. Late addition of alkalis has caused extensive retrogression in the high-grade rocks whereby the aluminous minerals (except pink andalusite) tend to become altered to muscovite. The zonal sequence (above) is examined in the light of the principle of metamorphic facies, and its relation to the well-known scheme of Barrow is indicated.

Introduction.

The Wantabadgery–Adelong–Tumbarumba district is situated in the South-Western Slopes region of New South Wales, nearly 300 miles from Sydney. Text-figure 1 indicates its geographical position. The main centres of population within the district are the townships of Adelong, Batlow and Tumbarumba. The north-western limit of the area examined is about six miles east of the city of Wagga Wagga.

No extensive systematic geological mapping had been undertaken previously in this area and thus the accompanying sketch map (Plate v) was compiled as a basis for the subsequent petrological studies (some of the country to the west of the present area has been mapped by Whiting, 1950). Field mapping was carried on at intervals over the period 1949–1952 and, in all, an area of about 900 square miles has been examined in more or less detail. The survey of the southern and south-western parts of the area has been of a reconnaissance nature.

The district studied constitutes only a part of a great belt of metasediments and granitic masses which extends from north-eastern Victoria across the Murray River into New South Wales and, trending in a north-north-westerly direction, may be followed (with some breaks) at least as far as Condobolin. At various localities, parts of the southern section of the belt have been examined in some detail, and here should be mentioned the pioneering work of A. W. Howitt (1888) and the later studies of Tattam (1929) and Crohn (1950) in Victoria, and of Joplin (1947) in the Albury–Jingellic region of New South Wales. All of this work displays evidence of the remarkable uniformity shown by many of the rock-types (both metasediments and granites) in this belt. Similar rocks have been found in a smaller, more easterly, parallel-trending belt which is well exposed in the Cooma district of New South Wales (Browne, 1914; Joplin, 1942).

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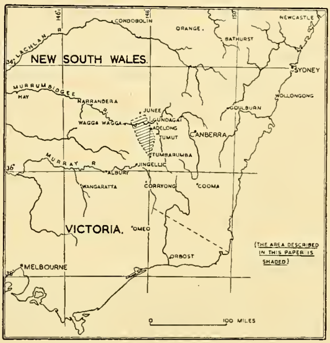
Geological Setting.

Of the metasediments and granitic rocks occurring in this area, only the former will be discussed in this paper. The granites are to form the subject of a later contribution but it may be useful to furnish here a brief account of the general geology of the region.

The country rocks are mainly of sedimentary origin and include arenites and argillites, now converted into phyllites, schists, and granulites by a metamorphism which was apparently in some way related to certain large granitic masses. Basic rocks of igneous origin occur in a belt which has been traced in a north-north-westerly direction from Batlow to beyond Adelong. Although intermediate to basic rocks have also been found in isolated bands away to the north-west near Nangus, the "basic belt" really loses its character just west of Bangandang Trig. Station and, for the most part, gives place to metasediments. Amphibolites and metamorphosed diorites or gabbros are the chief rock types in this "basic belt". The Adelong norite or hypersthene-gabbro forms a small mass in Adelong township which may be related to the other basic rocks.



Text-figure 1.—Locality map.

The basic rocks have been invaded by granite-granodiorite of the Ellerslie (west of Adelong, between the Nacka Nacka and Yaven Creeks) and Wondalga plutonic masses. The rocks of these two masses are practically identical and resemble specimens from the smaller Belmore mass (between Westbrook and Tarcutta). For this reason the three masses are grouped together in Plate v. Metamorphic activity at the contacts between these granites and the metasediments appears to have been variable but often relatively slight.

Another group of plutonic rocks constitutes the Wantabadgery and Green Hills (west of Batlow) masses. It also includes biotite granite-granodiorite types, but these rocks are lithologically quite distinct from the granites of the other group mentioned above. Highly altered inclusions of the metasediments are common in the Wantabadgery and Green Hills granites and the extensive metamorphism of the original sedimentary terrain was perhaps related to these two masses. The rough parallelism between the limits of the metamorphic zones and the outlines of the granite masses points to some relation between them. Field evidence suggests that the granites of this group were emplaced earlier than the Ellerslie, Wondalga and Belmore granites.

It is of interest to note that the Ellerslie-type plutonites are lithologically similar to the rocks of the Murrumbidgee batholith (Browne, 1943) north of Cooma, whilst the Wantabadgery–Green Hills-types resemble the Cooma gneiss (Browne, 1914) and the Albury gneiss (Joplin, 1947). A small portion of another plutonic mass (here called the Kyeamba adamellite mass) outcrops within the area mapped, but it has not been studied in detail (more of this mass was mapped by Whiting (1950)).

Tertiary basalt flows overlying auriferous deep-leads occur at Tumbarumba (Anderson, 1890; Booker, 1950). These have not been studied and their outcrop shown on Plate v is taken mainly from Booker's maps. Extensive alluvium of probable Tertiary–Recent age is found along the Murrumbidgee River and many of its tributaries.

Metasediments.

Variations in metamorphic intensity have wrought important mineralogical and textural changes in the metasediments, but throughout the area these rocks tend to preserve a certain uniformity in chemical composition. Probably the best approach to the study of the results of the metamorphism is by considering the reactions of members of groups of rocks with comparable chemical compositions (isochemical series) to the variations in metamorphic intensity. The terms pelite, psammopelite, and psammite were used by Joplin at Cooma and Albury, and other metamorphic petrologists have also employed them to denote isochemical groups. As understood by sedimentary petrologists, however, these terms denote a grain-size type rather than a chemical one, and to avoid confusion it seems necessary to state clearly the sense in which they are used. In the present case the classification is based on texture, but analytical work indicates that here there is a rough correlation between texture and composition, and so the terms can, for the most part, be taken as indicating chemical groups. Chemically, as well as texturally, there are gradations between the three types.

Of the members of the pelite-psammopelite-psammite series, the psammopelites are certainly the most abundant in this area. Pelites are quite common, but sand rocks (psammites) have a somewhat more restricted occurrence. The absence of coarse sediments (conglomerates) has been noted by most workers in this belt. In addition to these groups, red jaspers, a little limestone, and some serpentine-bearing siliceous rocks occur in the Nangus district on the north-eastern side of the present area. These rocks only outcrop within the low-grade zone of metamorphism.

Psammopelites and Psammites.

The psammopelites, in addition to their abundance, are of interest because of their lithology. They are characterized by an appreciable amount of silt-sand material (mainly quartz, some felspar) in an extensive micaceous matrix (representing the original clay fraction). Sorting has, in places, produced finely banded rocks in which the relative proportions of the silt-sand and clay fractions vary. These are like the banded psammopelites of Joplin (1942). Even in the more advanced stages of metamorphism such rocks may have their sedimentary banding preserved.

The more homogeneous (non-banded) psammopelites are usually more massive and less cleaved than their banded relatives but are equally widespread. In their case, however, there is a greater tendency for metamorphic processes to obliterate the original sedimentary features—as a rule the coarsest types preserving their individuality most tenaciously. The petrography and mineralogy of these rocks will be discussed in connection with the various zones in which they occur, but it may be worth while to note here several salient features. These sediments are characterized by abundant detrital quartz grains, usually rather angular and somewhat poorly sorted. Detrital felspar is widely distributed but is not really abundant (does not exceed 10% by volume). Small rock fragments are not uncommon in the sand fractions along with the quartz and felspar. All of this material is typically held in an argillaceous matrix.

Beds of such rock, often from a few inches to a few feet thick, alternate with slaty (pelitic) bands and may show such sedimentation features as current-bedding and graded-bedding. Very few small-scale slump-structures have been seen. The relatively unmetamorphosed representatives of the psammopelitic rocks may be regarded as subgreywackes following Pettijohn's (1949, p. 255) definition.

Table 1 gives analyses of psammopelites and sandier rocks from this area and from Cooma as well as a subgreywacke from Arkansas (U.S.A.) and an average of 371 sandstones. No. 10 represents a lime-rich type of sandy rock (now a granulite) from Cooma. Similar rocks have been found in this area near Mundarlo but none of these was analysed.

TABLE 1.

Analyses of Psammopelites and Psammites.

	1	2	3	4	5	6	7	8	9	10
SiO_2	68·17	69·98	74·59	76·28	79·37	84·21	73·64	74·43	84·86	71·26
Al_2O_3	16·76	14·66	12·71	12·87	11·47	9·12	13·89	11·32	5·96	12·42
Fe_2O_3	2·34	1·91	0·61	1·68	2·43	0·93	0·70	0·81	1·39	0·68
FeO	2·51	4·45	4·21	1·09	0·56	1·40	4·04	3·88	0·84	4·47
MgO	2·06	2·39	0·78	0·73	0·97	0·88	1·98	1·30	0·52	2·13
CaO	0·28	0·19	0·67	0·18	0·22	0·37	0·28	1·17	1·05	7·73
Na_2O	0·76	0·50	1·31	0·82	1·02	1·01	1·12	1·63	0·76	0·31
K_2O	3·08	3·92	3·29	3·67	2·50	1·23	2·88	1·74	1·16	0·01
H_2O+	2·59	0·89	1·29	1·90	0·79	0·55	0·42	2·15	1·47	0·19
H_2O-	0·38	0·18	0·17	0·36	0·25	0·28	0·07	0·20	0·27	0·02
TiO_2	0·88	0·71	0·63	0·27	0·53	0·21	0·63	0·83	0·41	0·47
P_2O_5	0·22	n.d.	n.d.	n.d.	0·10	0·11	n.d.	0·18	0·06	abs.
MnO	0·05	0·04	0·03	0·05	0·04	n.d.	0·06	0·04	tr.	0·55
CO_2	—	—	—	—	—	—	—	0·48	1·01	0·13
Etc.	—	—	—	—	—	—	—	0·29	0·10	—
	100·08	99·82	100·29	99·90	100·25	100·30	99·71	100·45	99·86	100·37

1. Fine-grained psammopelite (Biotite Zone). Por. 36, Par. of Yabtree, Co. Wynyard. Anal. T. G. Vallance.
2. Cordierite-rich granulite. East side of Por. 35, Par. of Dutzon, Co. Wynyard. Anal. T. G. Vallance.
3. Quartz-rich granulite. Por. 66, Par. of Cunningdroo, Co. Wynyard. Anal. T. G. Vallance.
4. Grey-green phyllite (very fine-grained psammopelite). Por. 187, Par. of Mundarlo, Co. Wynyard. Anal. T. G. Vallance.
5. Psammopelite (subgreywacke). Por. 30, Par. of Yabtree, Co. Wynyard. Anal. T. G. Vallance.
6. Quartz-rich psammite (Knotted Schist Zone). West side of Por. 56, Par. of Yabtree, Co. Wynyard. Anal. T. G. Vallance.
7. Corduroy granulite. Cooma area. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942: 168.
8. Subgreywacke. Near Mena, Arkansas. Anal. B. Bruun. Pettijohn, "Sedimentary Rocks", 1949, p. 256.
9. Average of 371 sandstones. *U.S. Geol. Surv. Bull.* 695, 1920: 539.
10. Amphibole-bearing granulite. Cooma area. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942: 167.

Pelites.

The more lowly metamorphosed pelites of this area occur as buff- to grey-coloured slates with good cleavage and fine grain-size. With increase in metamorphic grade they pass into phyllites and schists and finally in places into high-grade granulites. Throughout all these stages the pelites retain a certain chemical uniformity, as may be seen from the analyses of rocks from various parts of the metamorphic progression. In Table 2 pelites from other districts in the metamorphic belt are included for comparative purposes.

Examination of the analyses indicates that the pelites have a rather distinctive composition. Text-figure 2 graphically depicts this. A group of 29 analyses of pelites from the metamorphic belt (and from Cooma) has been plotted on an alkali-lime diagram along with analyses of slates and phyllites from various parts of the world, including the U.S.A., Wales, France, Germany, Victoria, and New South Wales. It can be readily seen that the pelites from the metamorphic belt tend to fall in the potash-rich, lime-poor field and are well away from the average shale and slate. Another feature of these pelites is their high alumina content.

Emmons and Calkins (1913) noted that the pelites of the Silver Hill formation (Cambrian) of the Phillipsburg area, Montana (see Table 2) were remarkably potash-rich and suggested that the original rocks may have been glauconitic. The composition of these rocks is roughly comparable with those now studied, but in view of the lack of an abnormal iron content there appears to be little evidence for a glauconitic origin